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ORIGIN OF THE PROBLEM: RAPPORTEUR'S REPORT

Malcolm Ross

Introduction. The Reserve Mining Co., in the processing of taconite iron ore quarried from the Peter Mitchell Pit, deposited the finely crushed waste rock into Lake Superior near Silver Bay Minnesota. In the early 1970's The U.S Environmental Protection agency filed a lawsuit against Reserve Mining Co., asking the court to force the company to stop dumping into the lake. On April 20, 1974, after a lengthy court battle, the U.S. District Court concluded that the Reserve Mining discharge into Lake Superior violated federal and state pollution laws and thus ordered Reserve Mining Co. to halt the lake disposal of taconite tailings. At the time many feared that some of the mineral particles contained in the tailings (alleged to be asbestos or asbestos-like) would cause human health problems. This Conference was thus convened to readdress the problem of the mineral content of the Biwabik Iron Formation and to whether any minerals contained in the ore could cause human disease. The four papers given in this session address the nature of the mineral particles in the taconite rock, the definition of the term "asbestos" and the history of the legal controversy over the possible health effects of certain mineral particles contained in the Biwabik iron range ores.

PAPER 1 - GEOLOGY OF THE BIWABIK IRON FORMATION AND DULUTH COMPLEX, Mark A. Jirsa, James D. Miller, Jr. and G.B. Morey

The Biwabik Iron Formation was a principal source of ore for the American steel industry during the twentieth century. The unaltered iron deposits, called taconite, contain approximately 30 percent iron and 50 percent SiO_2 . About 75 percent of the iron in taconite resides in the mineral magnetite, the remainder is largely in iron carbonate and several iron silicate minerals

At the east end of the Mesabi range where the Reserve Mining's Peter Mitchell Pit is located, the Biwabik Iron Formation has been metamorphosed by the intrusion of the Duluth Igneous Complex, the Complex being characterized by various combinations of olivine, pyroxene, and a variety of amphibole minerals. The possible presence of fibrous minerals in Biwabik rocks of the east Mesabi range, and their potential liberation by iron mining, has raised environmental health concerns and litigation. The amphibole minerals, some suspected to be fibrous, that have particularly come to the attention of the courts.

Biwabik Iron Formation is classified into four zones, each with a distinctive mineralogy:

Zone 1. The unaltered rocks contain quartz, magnetite, hematite, siderite, ankerite, talc, and the iron-silicate minerals chamosite, greenalite, minnesotaite, stilpnomelane, and talc. The minerals quartz, hematite, siderite, chamosite, greenalite, and some magnetite are considered primary minerals.

Zone 2. Transitional taconite contains mineral assemblages that are similar to the unaltered taconite of zone 1, but differs by the extensive replacement of quartz, and ankerite, the reduction of hematite to magnetite and the appearance of clinozoisite.

Zone 3. Moderately metamorphosed taconite is characterized by the development of the iron-rich amphiboles grunerite and cummingtonite, at the expense of original iron carbonates and silicates, and the associated production of calcite.

Zone 4. Highly metamorphosed taconite is completely recrystallized to a metamorphic fabric composed mainly of quartz, iron-bearing amphiboles (the grunerite-cummingtonite series and hornblende), iron-bearing pyroxenes (hedenbergite, ferrohypersthene), magnetite, and rare fayalite and calcite.

Paper 2 - OVERVIEW OF THE MINERALOGY OF THE BIWABIK IRON FORMATION, MESABI IRON RANGE, NORTHERN MINNESOTA

Peter L. McSwiggen and G.B Morey

The Biwabik Iron Formation is subdivided into four stratigraphic units (lower cherty, lower slaty, upper cherty, and upper slaty) and into four lateral mineralogical zones (1-4).

Zone 1, the westernmost zone, is characterized by the minerals quartz, magnetite, hematite, carbonates, talc, chamosite, greenalite, minnesotaite and stilpnomelane. Chamosite and greenalite are platy silicates, similar in physical properties to the micas, belonging to the septechlorite mineral group. Minnesotaite is also a platy mineral whose crystal structure is related but not identical to talc and is sometimes intergrown with talc. Stilpnomelane is a typically cryptocrystalline sheaf-like silicate found in a variety of textural settings. Commonly it has a pale brown or reddish brown color, but some varieties have a greenish brown color. Although granules composed entirely of stilpnomelane may occur, this mineral more commonly occurs as individual laths or radiating sheaves. Rarely, stilpnomelane also may be found within the cores of oolites along with fine-grained chamosite and minnesotaite

Zone 2, contains mineral assemblages similar to those observed in unmetamorphosed iron-formation, but exhibits evidence of extensive recrystallization of quartz and magnetite and the widespread replacement of the iron silicates by quartz and ankerite. Such features include granules of very fine-grained acicular minnesotaite and magnetite that are typically fractured. The fractures are in turn filled with tabular grains of minnesotaite.

Zone 3 is a moderately metamorphosed iron-formation and occurs about 2.3 miles from the contact with the Duluth Complex. It is marked by the appearance of a variety of amphibole minerals and by the disappearance of original iron carbonates and silicates. The development of grunerite-cummingtonite series amphiboles is pervasive throughout the zone. Grunerite first occurs in Zone 3 as small, tabular crystals surrounded by radiating fibrous sheaves composed of fine needles.

Zone 4 contains minerals that are completely recrystallized. The original silicate minerals have completely reacted and a new suite of minerals forms within the iron-formation. These

include grunerite, hornblende, hedenbergite, ferrohypersthene (ferrosilite), and fayalite. Grunerite in Zone 4 forms well developed acicular grains which gave way to the east to medium-size prismatic grains. The amphibole hornblende occurs as both prograde and retrograde phases. Prograde hornblende occurs intergrown with hedenbergite in the distal part of Zone 4. More commonly however, very fine acicular to fibrous hornblende is a retrograde phase that replaces hedenbergite, mainly at grain margins.

Since the Reserve controversy of the 1970s, morphological attributes of the cummingtonite-grunerite series have attracted considerable attention, primarily because of their general resemblance to some asbestos-like minerals. However, there appear to be no detailed studies regarding specific stratigraphic, compositional, and structural attributes of these Biwabik Iron Formation minerals. There is a general consensus, however, that these amphiboles formed under both prograde conditions, as metamorphic temperatures increased, and under retrograde conditions as temperatures decreased. To the east and immediately adjacent to the Duluth Complex, paragenetic relationships are complicated by the presence of retrograde cummingtonite. For example, virtually all of the prismatic cummingtonite at the Dunka River locality appears to be paragenetically late, having formed partly from fayalite, but mainly from ferrosilite and/or pigeonite. At somewhat lower temperatures, prismatic cummingtonite may be replaced by more magnesium-rich phases that have an acicular habit. At still lower temperatures prograde acicular grunerite may be replaced by acicular or fibrous cummingtonite.

Paper 3 - The Mineral Nature of Asbestos

Malcolm Ross, Arthur M. Langer, Gordon L. Nord, R.P. Nolan, R.J. Lee, D. Van Orden & John Addison

The various words used to denote the asbestos minerals, including asbestos, asbestus, asbestinon, asbest, asbeste, asbeston, abeston, amiantos, amiantus, amianthus, amiant, and amiante, can be traced back to the writings of the ancient Greek philosophers and their use of two words—**αμιαντος** and **ασβεστος**. The Greek word **αμιαντος** (transliterated as "amiantos"), when used as a noun, is synonymous with the English word asbestos, when used as an adjective it can mean pure or undefiled. The ancient Greek writers used the noun **ασβεστος** ("asvestos") to mean quicklime; a meaning retained in modern Greek. However, Pliny the Elder, apparently misunderstanding the use of this word by the early Greek philosophers, replaced the Greek noun for quicklime (**ασβεστος**) with the dubious Greek word **ασβεστινον** which he interpreted to mean a non-combustible material. Pliny then transliterated **ασβεστινον** into the Latin noun "asbestinon", alluding to an incombustible linen, cleansed by fire, and used as shrouds for royalty during cremation

The term asbestos is now used to describe a group of six commercially important minerals having many desirable industrial properties. Asbestos grows within shear planes, faults and folds of deformed rock, either perpendicular (cross-fiber) or parallel (slip-fiber) to the opening in the rock, however, the formation of fibrous minerals in nature is rare. The unique mineralogical characteristic common to all of the asbestos minerals is that their morphologic form or habit of crystallization is in the form of polyfilamentous fiber bundles. Commercial asbestos includes one serpentine mineral (chrysotile asbestos) and five amphibole minerals (anthophyllite, tremolite, actinolite, crocidolite and amosite asbestos). However, these five

amphiboles usually crystallize in non-asbestiform habits. These non-asbestos habits, on a population basis, lack the morphological appearance of asbestos and do not possess the desirable industrial properties.

The amphibole mineral group accounts for approximately 5% by volume of earth's crust. However, due to the rarity of the asbestiform growth in rocks, commercially viable deposits of asbestos are exceedingly rare. Limited amounts of asbestos were used in ancient times, but with the needs of modern industrial development in the last decades of the 19th Century, asbestos mining became commercially important. Historically, more than 95% of the commercially mined asbestos is chrysotile asbestos. The remaining 5% is amphibole asbestos, predominately crocidolite and amosite, although anthophyllite asbestos and tremolite asbestos have been mined to a very minor extent.

Knowledge concerning the elemental compositions and crystal structure of the amphibole and serpentine minerals developed in the 19th and 20th Century respectively. It was known to 19th Century mineralogists that minerals crystallizing in the asbestiform habit had higher tensile strength and flexibility than those crystallizing in the more common acicular or prismatic form. By the time of World War I the elemental composition of many amphiboles had been determined and analysis of the morphology of large single crystals clearly delineated the amphibole mineral class. By 1916, the chemical formula of tremolite amphibole was described and in 1929 B.E. Warren first described the crystal structure of an tremolite. By 1930 he reported on five more amphiboles crystal structures – kupferite, actinolite, hornblende, grunerite and anthophyllite. The amphibole group is made up of 27 separate mineral types with a large number of varietal species based on 23 chemical species. Amphiboles crystallizing in the asbestiform habit has the designation asbestos added after the mineral name.

The essential structural features of the amphibole group are: linked silica tetrahedral forming a double silica chain. Further, a double chain of octahedra is linked to this double silica chain. There are four dissimilar octahedral sites which accommodate several kinds atoms, including Mg, Fe, Al, Mn, Ti, Na, and Ca. Varying amounts potassium and sodium may also appear in the amphibole A-sites located between the linked double tetrahedral-octahedral chains.

Chrysotile asbestos is a serpentine mineral and is one of the six minerals regulated under the asbestos standard and currently is only asbestos mineral of commercial importance. The crystal structure of chrysotile is composed of linked double sheets, one sheet of linked SiO₄ tetrahedra and the other of linked MgO₂(OH)₄ octahedral. The octahedral portion of the double layer is similar to that of brucite. The two sheets differ, particularly in their b-axis dimensions, causing an internal distortion. To compensate for the larger size of the octahedral sheet, the double sheets roll up into long cylindrical tubes, the octahedral sheet forming the exterior of the curved surface.

Paper 4 - The Origins of Public Concern with Taconite and Human Health: Reserve Mining and the Asbestos Case

Michael E. Berndt & William C. Brice

A review is given of the history of the Reserve Mining taconite mining operations at the Peter Mitchell Pit and of the lengthy court case that examined the possible human health effects of certain mineral particles contained within the taconite waste rock that was deposited into Lake Superior. Mineral particles belonging to the amphibole group were alluded by some to be asbestos or asbestos-like, and when ingested by drinking Lake Superior water thought to cause cancer.

Iron ore deposits were first discovered in Minnesota in the 1860's and until the 1940's most of the ore was unmetamorphosed "soft ore" containing much hematite (Fe_2O_3). In the 1940's techniques for processing taconite rock ("hard ore") was developed, removing the iron-bearing magnetite by magnetic separation from the crushed rock that also contained various silicate minerals including amphiboles. Reserve Mining shipped its first taconite ore pellets in 1955. Alleged polluting of Lake Superior by ore tailings was reported in 1968 and State Court proceedings were initiated soon afterward. In 1972 the U.S. EPA filed suit against Reserve Mining in U.S. District Court and the trial began in August of 1973. Phillip Cook reported in a June 1973 press release that the Lake Superior water contained asbestos. In April 1974 Judge Miles Lord issued an injunction for the immediate closing of the Reserve Mine, but a temporary stay was obtained by Reserve so the Company could develop a landfill for waste rock disposal. The landfill was finally approved by the Minnesota Supreme Court and permits were sued for a Milepost 7 Tailing Disposal Facility. This facility was completed in March of 1980 and discharge of waste rock into Lake Superior ended. By 1986 Legal settlement with Reserve was reached, but without a clear mineralogical description of asbestos or asbestos-like minerals in the waste rock or on the health effects that might ensue from drinking the Lake Superior waters. One of the Reserve Mining parent companies, LTV Steel, declared bankruptcy in 1989 and the mining facility was closed. The company was sold to Cyprus Minerals, Inc. in 1989 and was later sold to Cleveland-Cliffs; the mine currently operating as Northshore Mining. The true nature of the minerals contained in the taconite rock remains unresolved.